

WHAT IS CLAIMED IS:

1. A method for manufacturing calcium fluoride single crystal comprising the step of cooling the
5 calcium fluoride single crystal so that maximum shear stress inside the calcium fluoride single crystal caused by thermal stress is approximately equal to or smaller than critical resolved shear stress (τ_c) in a $\langle 1\ 1\ 0 \rangle$ direction of on a $\{0\ 0\ 1\}$ plane of the calcium
10 fluoride single crystal.

2. A method for manufacturing calcium fluoride single crystal comprising the step of cooling the calcium fluoride single crystal with variable cooling
15 rates so that throughout temperature in said cooling step, maximum shear stress inside the calcium fluoride single crystal caused by thermal stress is approximately equal to or smaller than critical resolved shear stress (τ_c) in a $\langle 1\ 1\ 0 \rangle$ direction of on
20 a $\{0\ 0\ 1\}$ plane of the calcium fluoride single crystal and maintained to be an approximately constant ratio.

3. A method for manufacturing calcium fluoride single crystal comprising the step of cooling the
25 calcium fluoride single crystal so that maximum shear stress inside the calcium fluoride single crystal caused by thermal stress is 1.2 times as large as

critical resolved shear stress (τ_c) or smaller in a $\langle 1\ 1\ 0 \rangle$ direction of on a $\{0\ 0\ 1\}$ plane of the calcium fluoride single crystal.

5 4. A method for manufacturing calcium fluoride single crystal comprising the step of cooling the calcium fluoride single crystal with variable cooling rates so that throughout temperature in said cooling step, maximum shear stress inside the calcium fluoride
10 single crystal caused by thermal stress is 1.2 times as large as critical resolved shear stress (τ_c) or smaller in a $\langle 1\ 1\ 0 \rangle$ direction of on a $\{0\ 0\ 1\}$ plane of the calcium fluoride single crystal and maintained to be an approximately constant ratio.

15

 5. A method according to any one of claims 1 to 4, wherein said cooling step is included in a cooling step after crystal growth, a cooling step after annealing, a cooling step after mechanical processing
20 of crystal, a cleansing step of a crystal surface, or a coating step to a crystal surface.

 6. A crystal growth apparatus comprising a cooling mechanism necessary to execute the method
25 according to any one of claims 1 to 4.

7. An anneal apparatus for annealing grown calcium fluoride single crystal, said anneal apparatus comprising a cooling mechanism necessary to execute the method according to any one of claims 1 to 4.

5

8. An antireflection coating forming apparatus comprising a cooling mechanism necessary to execute the method according to any one of claims 1 to 4.

10 9. Calcium fluoride single crystal manufactured by the method according to any one of claims 1 to 4.

10. Calcium fluoride single crystal for photolithography, wherein critical resolved shear
15 stress (τ_c) in a $\langle 110 \rangle$ direction on a $\{001\}$ plane of the calcium fluoride single crystal is approximately equal to or larger than shear stress (τ) expressed by $\tau = 1.5E - 2 \cdot \exp(3E3 \cdot T^{-1})$, where τ is shear stress (MPa) and T is average temperature (K) of the calcium
20 fluoride.

11. Calcium fluoride single crystal according to claim 10, wherein said calcium fluoride single crystal for photolithography has a diameter having Φ 300 mm or
25 larger and is used for a specific wavelength band less than 160 nm.

12. Calcium fluoride single crystal according to claim 10, comprising one or more types of additional elements with concentration of 20 ppm or larger.

5 13. Calcium fluoride single crystal according to claim 12, wherein the additional elements include strontium of concentration of 20 to 600 ppm.

10 14. A method for improving critical resolved shear stress of each slip system in the calcium fluoride single crystal by adding an additional element.

15 15. A method according to claim 14, wherein the additional element includes strontium.

16. An optical system comprising an optical element made of calcium fluoride single crystal according to claim 9.

20 17. An optical system comprising an optical element made of calcium fluoride single crystal according to any one of claims 10 to 13.

25 18. An exposure apparatus comprising an optical system according to claim 16.

19. An exposure apparatus comprising an optical system according to claim 17.

20. A device manufacturing method comprising the
5 steps of:

exposing an object using the exposure apparatus according to claim 18; and

performing a predetermined process for the object that has been exposed.

10

21. A device manufacturing method comprising the steps of:

exposing an object using the exposure apparatus according to claim 19; and

15 performing a predetermined process for the object that has been exposed.